§20. Numerical Analysis of Impurity Transport in Ergodic Layer of LHD

Kobayashi, M., Feng, Y. (MPI, IPP), Masuzaki, S., Yamada, H., Ohyabu, N., Morisaki, T., Komori, A., Motojima, O., LHD Experimental Group

Impurity transport model in ergodic layer can be formulated as follows[1) 2)]: From the parallel momentum equation for impurity[3)], dominating terms are found to be friction force and ion thermal force. The force balance of these two terms gives the expression for impurity velocity along field lines,

$$V_{z//} \approx V_{i//} + C_i \frac{\tau_s}{m_z} Z^2 \nabla_{//} T_i , \qquad (1)$$

where $V_{z//}$, $V_{i//}$, T_i are parallel flow of impurity, of background plasma and ion temperature. τ_s, m_z and Z represent collision time of impurity and plasma ion, mass and charge state of impurity, respectively. C_i is numerical factor. The first and second terms on the right hand side are contributions from friction and ion thermal force, respectively. Here it is noted that $V_{z//}$ becomes independent of Z due to Z^2 in denominator of ts. The continuity equation of impurity in radial direction in ergodic layer is written as,

$$\frac{\partial}{\partial r}\left(\Theta n_I V_{z//} - D_I \frac{\partial n_I}{\partial r} \right) = 0, \qquad (2)$$

here r is minor radius of plasma. Source term is neglected because of usually very short ionization mean free path of neutral impurity. nI and DI are impurity density summed up over all charge states and cross field diffusion coefficient of impurity. Θ is field line pitch inside remnant islands in ergodic layer, defined as dr/dl with dl being parallel length along island separatrix for radial extension dr .The equation can be integrated to give,

$$n_I(r) = n_I(a) \exp\left(- \int_r^a \frac{\Theta V_{z//}}{D_I} dr \right), \qquad (3)$$

here a is outermost boundary of ergodic layer. The equation shows that with outward impurity flow, $V_{z//} > 0$, the impurity is retained (screened) in the ergodic layer. The condition to have positive $V_{z//}$ is that friction force dominates over thermal force,

$$\frac{\text{friction force}}{\text{thermal force}} \sim \frac{5/2 n_i T_i V_{i//}}{\kappa_i^0 T_i^{2.5} \nabla_{//} T_i} > 1. \qquad (4)$$

In order to investigate the impurity transport properties in the ergodic layer of LHD, the 3D numerical edge transport code, EMC3-EIRENE, is applied to the helical divertor configuration. The realistic three dimensional geometry of magnetic field line structure of the edge region as well as vessel wall/divertor plates are precisely treated by the code. The conservation form of Braginskii equation of mass, momentum and energy is solved by Monte Carlo scheme. The computational domain starts from last closed flux surface (LCFS) at upstream and covers entire ergodic layer. The background plasma is calculated by adjusting cross-field transport coefficients so as to reproduce edge temperature and density profiles in experiments. Upstream density, n_{LCFS}, is specified as a boundary conditions, and input power is used to give energy flux at LCFS. Both parameters are obtained from experiments. Bohm boundary condition is applied at the divertor plates. In the present analysis, carbon is selected as impurity, which is main impurity species in LHD because of divertor plates made of carbon. The neutral carbon is released from divertor plates according to the plasma flux distribution. Sputtering coefficient is fixed to 0.02 for the present computations. In order to investigate the impurity transport characteristics, n_{LCFS} is scanned while input power is fixed to 8 MW.

The obtained carbon density profiles is plotted in Fig. 1 in a poloidal cross section for different background plasma densities. At low density, n_{LCFS}= 2×10^{19} m^{-3}, the carbon is accumulated around LCFS, which is the boundary of the computational domain. This is attributed to the dominant thermal force caused by parallel temperature gradient, the direction of which is upward due to the temperature drop toward divertor plate. At higher density, n_{LCFS}=4×10^{19} m^{-3}, on the other hand, the friction force starts to dominate over thermal force due to increasing collisionality. The friction force exerted by the background plasma flow directs toward divertor plate. As a consequence, the impurity is effectively retained (screened) in the very edge of ergodic layer at the higher density, as shown in the figure.

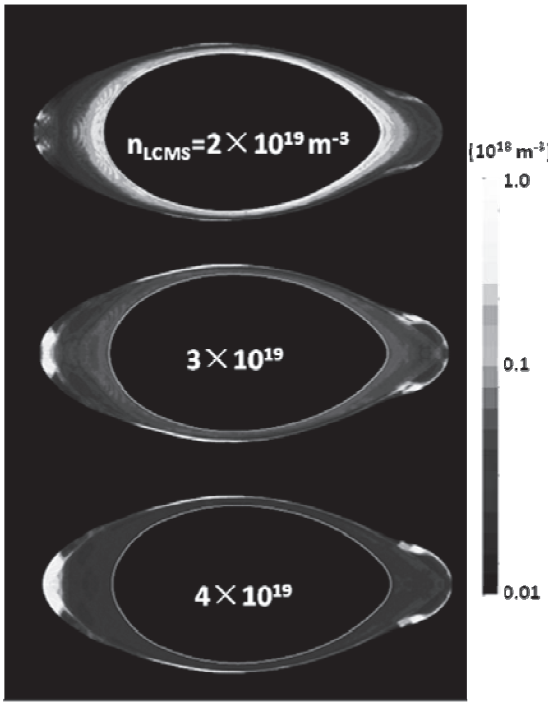

Fig. 1 Carbon density profiles in poloidal cross section obtained by EMC3-EIRENE for different background densities.

1) Kobayashi, M. et al., Contrib. Plasma Phys. **48** (2008) 255.
2) Feng, Y. et al., Nucl. Fusion **46** (2006) 807.
3) P.C. Stangeby and J.D. Elder, Nucl. Fusion **35** (1995) 1391.